



Optimization of Compressive Strength from the Combination of Sugar Cane Bagasse and Cashew Nut Shell Composite Briquettes Using D-Optimal Design

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Abstract

This study aimed at optimizing the mixture of Cashew Nut shells (CNS) and Sugarcane Bagasse (SGB) composites briquettes using starch as binder on the compressive strength using D-optimal under the custom design of the design expert (12.0.1.0). CNS and SCB were obtained from Olam Industry and Lafiagi Kwara State. The two biomasses were sun-dried for four days to reduce moisture content. CNS was carbonized in a furnace at a temperature 250°C for 3 hours. The two biomasses were pulverized into three different particle sizes 0.3mm 0.6 mm and 0.9mm which were mixed together by following the result generated by the design of experiment (D-optimal). A total number of 19 experimental runs from D-optimal were used to produce the briquettes of CNS and SCB composite briquette where the compressive strength of each of the briquettes were determined based on ASTM D 2166-85 standard. Run 10 (44% CNS, 19% SCB, 37% binder, Particle size 0.3 mm) gave the highest compressive strength of 1.09 MPa. The regression coefficient (R^2) of the model equation obtained for the process is 0.8991, while the predicted R^2 is 0.6314 which shows a reasonable agreement with the adjusted R^2 (0.7982). The result of optimization indicates the mixed ratio of CNS, SCB, binder and particle size influences the compressive strength. This study shows the efficacy of using CNS, and SCB in producing composite briquettes to achieve the highest compressive strength and improve transportability and marketability of the briquettes.

Keywords: Biomass, Cashew nutshell, Sugarcane Bagasse, Briquettes, Cassava, D-optimal Optimization, compressive strength.

Introduction

Biomass is one of the most important renewable sources of energy which has been rated to be the world's fourth-largest energy source after coal, crude oil, natural gas. Biomass materials include SCB and CNS municipal solid waste and waste paper, rice husk, sawdust which are discarded as waste (Dickenson, 2016). It was reported that some of these wastes can be used as a fuel energy by converting the biomass into briquettes through densification (Babajide. *et al.*, 2018). Briquetting is a mechanical method used in compacting biomass into a product of high

density mass for the purpose of achieving high calorific value, easy storage and transportation (Bhattacharya. *et al.*, 2000 and Ajit. *et al.*, 2017). Briquettes have many advantages as a fuel over initial raw biomass in terms of safe, clean and environmentally friendly (Dianne Pummer. *et al.*, 2020), reduction in degradation problem as well as mitigate climatic change and pollution (Okello. *et al.*, 2013) and easy storage and transportation (Kaliyan and Morey, 2009). Briquettes as a solid fuel can be used in large industry for power generation (Manyuchi. *et*

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al., 2018). For this investigation, due to the availability and abundance of each biomass type in Nigeria, Sugarcane bagasse and Cashew nut shell were used to produce composite briquettes.

Compressive strength is one of the crucial factors in determining the briquette durability. It assists in determining the ability of briquettes to be parked and transported easily without breaking (Dickenson, 2016). To achieve efficient handling, storage, transportation and as well as producing briquetting of economical value, it is very important to investigate the optimal compressive strength of the produced briquettes. Design of experiment will be helpful in investigating and optimizing the mixing effects of several process variables influencing responses with a minimum number of experimental runs while varying the variables concurrently.

In a combined experiment, the measured response is assumed to depend only on the relative ratio of the component in the mixture, compared to Taguchi and factorial methods (Oladosu. et al., 2016).

The aim of this study is to optimize the compressive strength of CNS and SCB composite briquettes using starch as binder.

Material and Method

Cashew Nut shells were collected from Olam Edible nut industry in Afon, Asa Local

Government Area Kwara State and sugarcane bagasse were obtained at Lafiagi Kwara State, CNS was sun dried for 4 days and then carbonized in a furnace at a temperature of 250 °C for 3 hours (Kimutai and Kimutai, 2019). CNS and the SCB were pulverized into smaller pieces using hammer mill and sieved to obtain samples of three different particle sizes: 0.3 mm, 0.6 mm, 0.9 mm. The starch obtained from cassava industry in Ilorin, Kwara State was turned into a smooth paste by dissolving the weight in gram of each of the binder obtained by the design of experiment (DOE) in 12 cm³ of cold water and then 80 cm³ of boiling water which was stirred gently while hot to form a smooth homogeneous gelatinized starch solution.

Experimental Design

D-optimal Design under Custom Design Methodology was used to optimize the mixture of CNS, SCB, binder and the process factor. The design was performed using the Design Expert software (12.0.1.0). The minimum and the maximum level of the component (CNS, SCB and binder) were in the range of 0-100% while the factor levels were range 0.3-0.9mm. A total number of 19 experimental runs were generated from the D-optimal but all aggregated to 100% and at each experimental run for the various particle size as shown in Tables 1(a) and 1(b), which were used to produce the briquettes of CNS and SCB composite.

Table 1(a): Design Entries of Determining Factors for Briquettes Production Process and their Units

	Mixture Component	Units	Minimum value	Maximum value
Factor	CNS	%	40	70
	SCB	%	10	30
	Binder	%	10	40
	Particle Size	mm	0.3	0.9

Table 1(b): Design Matrix of Percentage Composition of SCB, CNS with Particle Size, and Compressive Strength Response

	Component 1	Component 2	Component 3	Factor 4	Response 1	Response 2
Run	CNS	SCB	BINDER	Particle Size		Compressive strength
	%	%	%	Mm		MPA
1	48	12	40	0.3		
2	53	10	37	0.6		

3	55	10	35	0.9		
4	41	19	40	0.9		
5	55	21	24	0.9		
6	70	13	17	0.6		
7	70	14	16	0.9		
8	40	20	40	0.6		
9	67	10	23	0.3		
10	44	19	37	0.3		
11	63	27	10	0.6		
12	63	10	27	0.6		
13	42	30	28	0.9		
14	44	30	26	0.6		
15	70	20	10	0.3		
16	55	20	25	0.6		
17	40	26	34	0.3		
18	55	20	25	0.3		
19	61	29	10	0.9		

Determination of Compressive Strength

The compressive strength is one of the crucial factors in determining the briquette's durability. It assists in determining the ability of briquettes to be packed and transported easily without breaking (Dickenson, 2016). The compressive strength of briquettes was determined according to ASTM D 2166-85 (2008) using an Instron Universal Testing Machine with a load cell of 50 KN. The flat surface of the briquette sample was placed on the horizontal metal plate of the machine. A load was applied at a constant rate of 90 N/min until the briquette failure occurred by cracking.

Statistical Analysis

The data (response) obtained from the mixed ratio of CNS, SCB, and binder on the compressive strength was analyzed statistically using facilities embedded in the Design-Expert software version 12.0.1.0. The quality of the fit of the model was evaluated using test of significant and Analysis of Variance (ANOVA).

Optimization Procedures of Compressive from CNS and SCB Composite Briquettes

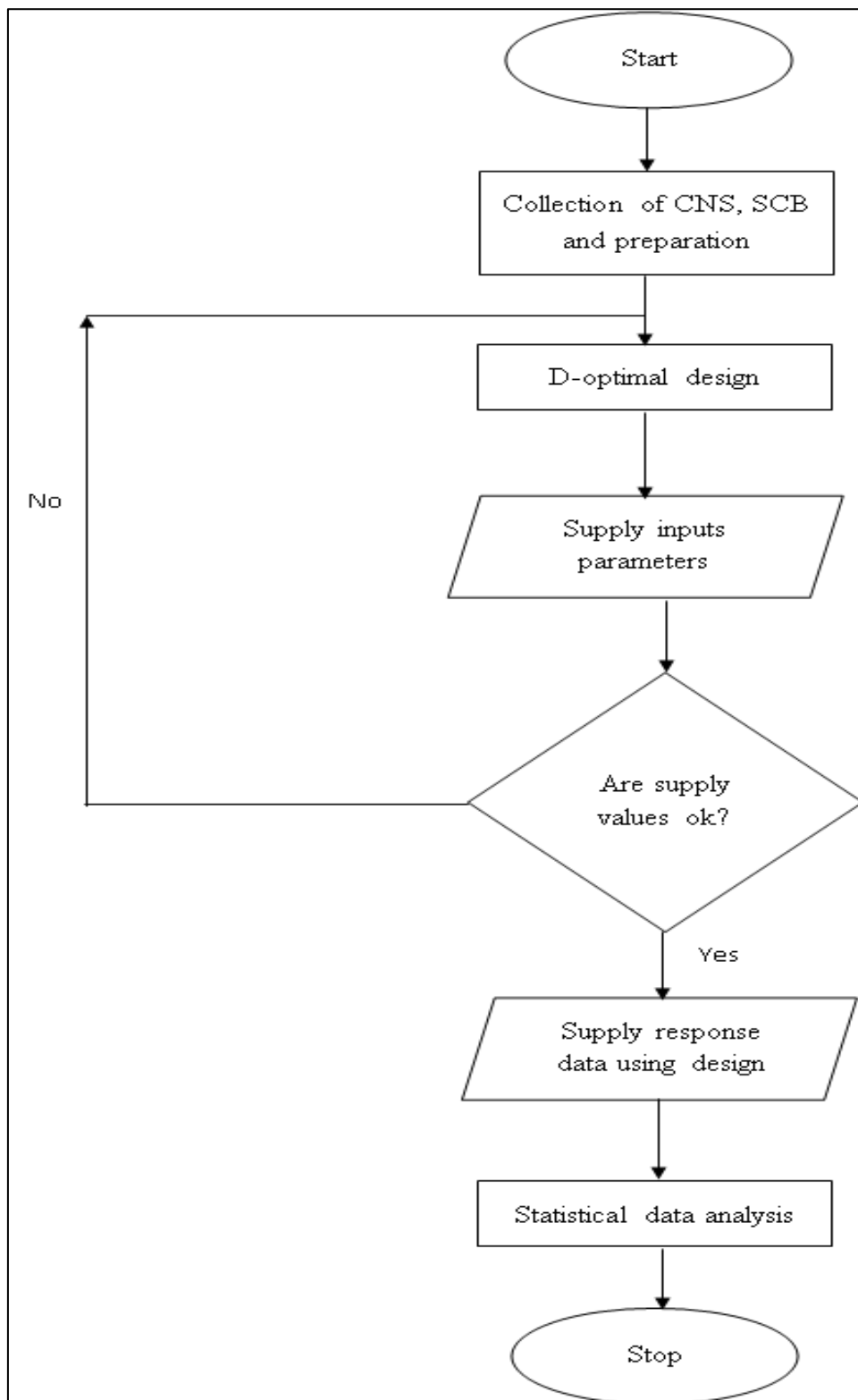
The highest compressive strength was investigated from the briquettes made from CNS and SCB composite which lead to the preparation of algorithm which was translated into DOE version 12.0.1.0 version.

The flow chart upon which the algorithm was based is shown in Figure 1.

1. Collection of CNS from Olam Edible Nut Industry in Afon Asa Local Government, Kwara, Nigeria
2. Collection of SCB from Lafiagi, Kwara State, Nigeria
3. CNS and SCB were sun-dried, hammer milled and sieved to various particle sizes ranging from 0.3 to 0.9mm
4. Starch as a binder was obtained from the manufacturer
5. Click D- optimal design under combined methodology using design expert software version 12.0.1.0
6. Select the number of mix components and enter (CNS,SCB, binder) and their corresponding level (low and high) in the dialog box provided
7. Select the numerical factor and enter particle sizes and its level
8. Select the number of response (1) and type compressive strength in the dialogue box provided and then click continue
9. Enter the response data obtained in the design layout view
10. Click on the compressive strength under analysis and follow the steps displayed at button across the top of the view as follows:
11. Click on square root under transformation

- 12. Click on fit summary to evaluate mixture process crossed model
- 13. Click on model order and desired terms from list;
- 14. Click on analysis of variance ANOVA to analyze the chosen model and view results

- 15. Click on diagnostic to evaluate model fit and transformation choice with graphs
- 16. Click on model graph to interpret and evaluate the model.



Ignition Time

Ignition time is the time taken for the briquettes to ignite and was determined by taking the sample of each of the briquette to be ignited to a free corner and ignite. The time taken for flame to ignite the briquette was recorded as the ignition time using stop watch (Ajiboye. *et al.*, 2016).

Water Boiling Tests of the Briquette Sample

150g of each of the briquette sample was used to boil 100cm³ of water in a kettle and the time

taken for each of the briquette sample to boil 100cm³ of water was taken Using stop watch (Imeh. *et al.*, 2017).

Results and Discussion

Optimization of Binder, CNS and SCB Composite Briquettes

Nineteen experimental runs using D-optimal design for mixture and factor study and the compressive strength response as shown in Table 2.

Table 2: Design Matrix of Percentage Composition of SCB, CNS and process factor Particle Size on the Compressive Strength response

Run	Component 1		Component 2		Component 3		Factor 4		Response 1	
	CNS	%	SCB	%	BINDER	%	Particle	Size,	Compressive	strength,
							mm		MPa	
1	48		12		40		0.3		0.59	
2	53		10		37		0.6		0.36	
3	55		10		35		0.9		0.51	
4	41		19		40		0.9		0.67	
5	55		21		24		0.9		0.80	
6	70		13		17		0.6		0.62	
7	70		14		16		0.9		0.59	
8	40		20		40		0.6		0.63	
9	67		10		23		0.3		0.82	
10	44		19		37		0.3		1.09	
11	63		27		10		0.6		0.86	
12	63		10		27		0.6		0.16	
13	42		30		28		0.9		0.16	
14	44		30		26		0.6		0.7	
15	70		20		10		0.3		0.74	
16	55		20		25		0.6		0.87	
17	40		26		34		0.3		0.71	
18	55		20		25		0.3		0.77	
19	61		29		10		0.9		0.71	

As shown in table 2 Run 10 (44% CNS, 19% SCB, 37% binder, Particle size 0.3 mm) has the highest compressive strength of 1.09 MPa. It has been reported by Kumutai and Kumutai, (2019) that the smaller the particle size and the higher the percentage of binder ratio lead to highest compressive strength of the briquettes and this favor Run 10. Run 12 (63% CNS, 10% SCB, 27% binder and particle size 0.6 mm) and Run 13(42% CNS, 30% SCB, 28% binder and particle size 0.9 mm) have the same lower compressive strength of 0.16 MPa. The same

compressive strength of Run 13 to that of Run 12 may be due to high SCB which has lignin content in it that play a vital role in binding agent and also the presence of high percentage of binder which is greater than that of Run 12 in its formulation. The lowest compressive strength in Run 12 and 13 is not desirable as this will lose their market value as a result of breakability during transportation. Run 10 were considered for further studies as a result of its highest compressive strength.

The statistical analysis was developed to be applicable for the compressive strength and it was found to have (R^2) of 0.8991 and adjusted (R^2) of 0.7982 which shows that the predicted (R^2) of 0.6314 is in reasonable agreement as the difference is less than 0.2. The “adequate precision” measures the signal to noise ratio

and a ratio greater than 4 is desirable, therefore, the ratio (12.1325) in the analysis indicates that the model can be used for navigation of design space. ANOVA results for cubic mean mode are tabulated in Table in table 3.

Table 3: ANOVA Results for Cubic Mean Model

Response Compressive Strength	Source	Sum of square	Df	Mean square	F-value	P-value
	Model	0.8654	9	0.0962	8.91	0.0016*
	Linear model	0.0571	2	0.0282	2.64	0.1249
	AB	0.1811	1	0.1811	16.78	0.0027*
	AC	0.2050	1	0.2050	19	0.0018*
	BC	0.2406	1	0.2406	22.29	0.0011*
	ABC	0.1486	1	0.1486	13.77	0.0048*
	AB(A-B)	0.3101	1	0.3101	28.74	0.0005*
	AC(A-C)	0.2117	1	0.2117	19.62	0.0016*
	BC(B-C)	0.1044	1	0.1044	9.67	0.0125*
	Residual	0.0971	1	9	0.0108	
	Core total	0.9625	1	18		

*Significant $R^2 = 0.8991$, Adjusted $R^2 = 0.7982$, Predicted $R^2 = 0.9691$, Adequate Precision = 12.1325, Standard deviation = 0.1039, Mean = 0.6505, C.V% = 15.97

Table 3. Shows that “Model F-value of 8.91 indicates that the model is significant as the value of “prob>f” less than 0.05 indicated. There is only a 0.16% chance that an F-value this large could occur due to noise. The analysis explains that the linear terms which are the parameters A, B, AB, AC, ABC ,

$AB[A - B], AC[A - C], BC[B - C]$ are significant model terms.

The developed cubic model showing the relationship between the compressive strength and the coded are shown in equation 1

$$\text{Compressive Strength} = 7.34819 \times A - 37.1909 \times B - 0.128194 \times C + 62.1461 \times AB - 13.6157 \times AC + 73.5378 \times BC - 58.5164 \times ABC - 75.9747 \times AB[A - B] - 15.6611 \times AC[A - C] + 40.3702 \times BC[B - C]. \quad 1$$

Where A is cashew nut shell, B is sugarcane bagasse, C is binder. Figure 2 shows the response surface plots of residual vs normal plot of residual for all responses indicating the adequacy of the model.

The compressive strength of briquettes with lower particle sizes is strong. This is due to the smaller inter particle gaps between the lower particle size briquette. As a result, the particles are easily packed together, resulting in homogeneity and cohesiveness in bonding formation and high compressive strengths.

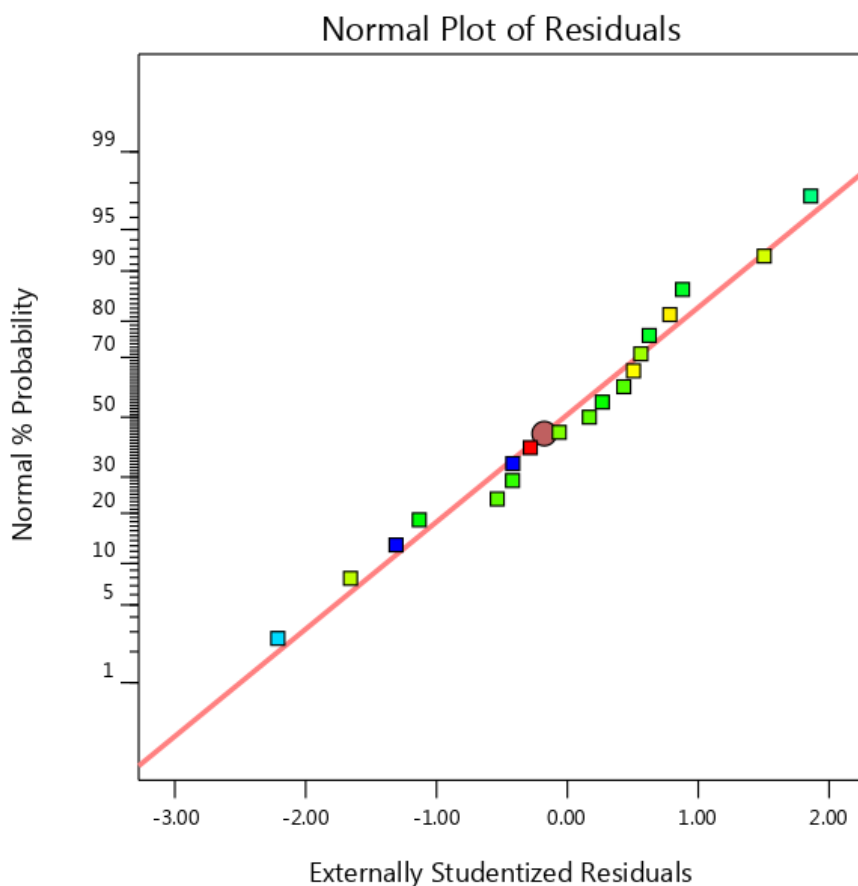


Figure 2: Normal Probability of the Experimental Result for Compressive Strength

Ignition Time

The highest ignition time of 32 seconds was observed from Table 4 at Run 7(70% CNS, 14% SCB, 16% binder, 0.9mm particle size) and the lowest ignition time of 19 seconds was recorded at Run 17(40% CNS, 26% SCB, 34% binder and 0.3 mm particle size). The lowest ignition time obtained is as a result of the smaller particle size. The result obtained is in agreement with the previous studies of Ajiboye. *et al.*, (2016) that particle size is directly proportional to the ignition time i.e. the larger the particle size, the higher the ignition time. The lowest ignition time obtained from this study show that briquettes produced are good for domestic use. This results is in agreement with the results

obtained by kimutai and Kimutai, (2019) that briquettes with higher percentage of binder ratio have the least ignition time.

Water Boiling Test

Table 4 shows that Run 17 (40%CNS, 26%SCB and 34% binder, 0.3mm particle size) has the lowest water boiling time of 20 minutes while Run 7 (70% CNS, 14% SCB, 16% binder and 0.9 mm particle size), has the highest water boiling time of 30 minutes. The briquettes water boiling time increases with an increase in particle size and increase in binder ratio. This result agrees with the results obtained by kimutai and Kimutai, (2019) that the addition of binder improves the burning rate of the briquettes.

Table 4: Energy Evaluation Analysis of CNS and SCB composite briquettes

Run	CNS (%)	SCB (%)	Binder (%)	Particle Size (mm)	Ignition Time (%)	Water Boiling Time (min)
1	40	12	40	0.3	21	23
2	53	10	37	0.6	24	22
3	55	10	35	0.9	28	26
4	41	19	40	0.9	27	25
5	55	21	24	0.9	25	27
6	70	13	17	0.6	27	24
7	70	14	16	0.9	32	30
8	40	20	40	0.6	23	26
9	67	10	23	0.3	20	22
10	56	30	14	0.3	23	22
11	63	27	10	0.6	20	21
12	63	10	27	0.6	22	24
13	42	30	28	0.9	29	30
14	44	30	26	0.6	31	29
15	70	20	10	0.3	21	21
16	55	20	25	0.6	24	30
17	40	26	34	0.3	19	20
18	55	20	25	0.3	21	23
19	61	29	10	0.9	31	28

Conclusion

The result of optimization shows that the mixed ratio of CNS, SCB and binder with the smaller particle size played a major role in determining the compressive strength of the briquettes produced. The optimal mix ratio that gives the best compressive strength was Run 10 (44% CNS, 19% SCB, 37% binder and 0.3 mm particle size) with the highest compressive strength of 1.09 Mpa. Run 17 (40% CNS, 26% SCB and 34% binder, 0.3mm particle size) gave the lowest ignition time and the shortest boiling time of 19 seconds and 20 minutes. The model obtained has provided a basis for selecting optimum mixture of CNS, SCB, binder and particle size for obtaining highest compressive strength.

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